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A STUDY WITH THE ECHELON SPECTROSCOPE OF CERTAIN LINES IN THE SPECTRA OF THE ZINC ARC AND SPARK AT ATMOSPHERIC PRESSURE.

By Norton A. Kent.

With two Plates.

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A STUDY WITH THE ECHELON SPECTROSCOPE OF CERTAIN LINES IN THE SPECTRA OF THE ZINC ARC AND SPARK AT ATMOSPHERIC PRESSURE.

By Norton A. Kent.

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In November, 1907, the writer published, in collaboration with one of his graduate students, an article [1] attempting to meet certain objections made by Keller [2] to the method of procedure adopted by the writer in certain former work [3] upon the question of the relative wave-lengths of certain lines in the spectrum of titanium and zinc as developed by the arc and spark discharge in air at normal pressure. That displacements of the spark lines to the red from the position of the corresponding arc lines actually existed on the photographic plates obtained, is regarded by the writer as unquestionably proven. It is certain, also, that the displacements were not due to any incorrect experimental procedure.

It appeared to be worth while to study the matter further, seeking to ascertain, if possible, the cause of these displacements. As the echelon spectroscope had revealed structure in the lines of metallic spectra both in Plücker tubes and in the arc in vacuo and at normal atmospheric pressure[4], it seemed advisable to use this instrument to study the spark, noting the change in the form of the image as a function of the constants of the electric circuit. The titanium lines λλ 3900 and 3913, formerly studied in detail, presented difficulties because of their short wave-lengths; therefore, it appeared best to concentrate the work upon zinc.

A brief survey of the most important results in the case of this metal recently obtained by various observers is thus in order.

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1 These Proceedings, **43**, No. 11, Nov. (1907).

2 Ueber die angeblicke Verschiebung der Funkenlinien, Inaugural Dissertation, Christian Keller.

3 These Proceedings, **41**, No. 10, July (1905).

4 Janicki, Annalen der Physik, **19**, 36–79, Jan. (1906).
Nutting, Astrophysical Journal, **23**, No. 1, Jan. (1906).
Nutting, Bulletin Bureau of Standards, **2**, No. 3, Dec. (1906).

Historical Survey.

Houston [5] who notes the changes which take place in the reversal system as seen by an echelon when a zinc arc "begins to hiss," speaks of the "striking forms of reversal," the distances between the different components in the line varying in the different parts of the arc. With one of his arcs and a small amount of vapor, he obtained the three blue lines of zinc "without reversals." Under certain conditions the three blue lines were "all doublets with components of equal intensity."

Janicki [6] in his inaugural dissertation (**1905**) states that "an examination by the echelon of the lines of the zinc spectrum developed in a capillary tube of 0.3 mm. diameter with external electrodes at a temperature of about 460° showed them to be single lines."

Nutting,[7] in a paper on line structure, mentions the fact that Plücker tube spectra of rarefied gases moderately excited show narrow lines of the simplest structure, "but with a heavy current or capacity in parallel, if the pressure be greater than 3 or 4 mm. the lines broaden, and finally, with a spark in series with the tube, widen into a continuous spectrum, with the peculiar fluted appearance characteristic of spark lines."

He states further that "sparks between metallic electrodes give lines far too broad for use as monochromatic sources. They are never less than half a tenth-meter broad. The effect appears to depend chiefly upon the amount of capacity used, and is greatly heightened by the use of another spark in series; that is, *it is due to the steepness of the wave-front of the current wave.*[8] Inductance weakens the wings produced by capacity, and sometimes channels them, but never reduces a line to a simple structure. Occasional lines will appear to simply broaden out under the violence of the discharge, but ordinarily it is simply a case of the dark background — between spectra of different order — becoming luminous."

"Using a small current (0.02 amp.) of low voltage (5000) and low frequency (60) and a minimum of capacity, and electrodes of iron and brass, the spark lines were found to be still broad and diffuse. Lines due to impurities (sodium, for example) occasionally appear

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5 Philosophical Magazine, **7**, May (1904).
6 See Annalen der Physik, **19**, 36–79, Jan. (1906).
7 Astrophysical Journal, **23**, No. 1, Jan. (1906).
8 The italics are the writer's.

fairly sharp on but a faint background, but a number of tests indicated that it is impracticable to obtain narrow lines by introducing impurities into the spark."

Further, when discussing arc spectra in general, he writes: "The structure which a line exhibits depends primarily upon its intensity; that is, upon the amount of a substance vaporized and the intensity of its excitation in the arc"; and specifically, in the case of zinc:

"All four zinc lines are rather diffuse, and are usually found double or triple.* * * The blue lines, 4810, 4722, 4680, are broad and diffuse, and show a trace of structure on reversal."

In a general discussion attention is called to the fact that the structure of any one line is very variable, so much so that "we may hardly speak of any line as having a fixed definite structure, even with a minute specification of conditions of production."

Types of lines are classified according to structure and behavior, and the general conclusion drawn that to explain certain types — lines which, when single, under some conditions become double or triple, symmetrically or unsymmetrically, with receding components of various relative intensities — the old absorption theory of reversal is not satisfactory.[9]

In another paper [10] covering the results of a search for intense and yet "pure" light standards, Nutting, sketching the development of the typical normal line in either the open air arc or at pressures less than atmospheric, states:—"with increase of intensity the line broadens, and finally separates into two; * * * with further increase the two components continually broaden and separate"; and of highest "rank as to purity are the composite lines produced in the vacuum tubes measured between extreme components."

In a paper [11] on relative intensities of spectrum lines an attempt is made to show that the changes produced in spectra by varying current, capacity, inductance, temperature and pressure, may be accounted for by a single variable, or at most, two. He writes:—

"Several years ago the writer [12] gave the steepness of the wave-front through a gas as condition for the preponderance of the secondary over the primary spectrum. Crew [13] almost at the same time con-

9 Nutting advances a theory of broadening, doubling and reversal in the Astrophysical Journal of April (1906).

10 Bulletin Bureau of Standards, **2**, No. 3, Dec. (1906).

11 Nutting, Astrophysical Journal, **28**, 66 (1908).

12 Astrophysical Journal, **20**, 135 (1904).

13 Ibid., **20**, 284 (1904).

cluded that a 'high E. M. F., rapidly changing, is a probable *conditio sine qua non* for the appearance of spark lines in arc spectra.' Both might better have expressed their results in terms of potential gradient." * * * "The lowest gradients are obtained in heavy current arcs and Plücker tubes with wide capillary; in the former case the low gradient is due to the heavy current, in the latter to low gas-pressure. Higher potential gradients are obtained in arcs with very small current, Plücker tubes with fine capillaries and sparks with small capacity and large inductance. The highest potential-gradients are found in sparks and other interrupted arcs, the gradient increasing with the amount of capacity in circuit and with the impressed voltage. Gradients vary from about 20 to 80 volts per cm. in ordinary arcs and tubes up to thousands of volts per cm. in condensed sparks." * * * "Inductance reduces the gradient down to a minimum, beyond which it is inoperative." * * * "In the condensed spark without inductance, the front of the pilot discharge must have a potential-gradient not much below the dielectric strength of the intervening gas. The remainder of the discharge is probably at a very low gradient, approaching that of a direct-current arc. Hence such a spark gives both spark and arc lines. Inductance and resistance lower maximum gradients by smoothing out the current wave. The spectrum of a spark rendered dead beat by series resistance can scarcely be distinguished from that of a low direct-current arc."

In 1909 Janicki [14] writes on the structure of spectrum lines, giving the results of a study made with the Lummer-Gehrcke plate, the source being an arc at low pressure (0.1 mm. or less) in a special form of apparatus having an anode of the desired metal.

The three zinc lines in the blue are described as sharp and simple. They appeared at 0.3 amp., were good at 0.4 amp., and at more than 0.7 amp. were reversed in part.

In certain calcium lines the change of position of their satellites with increase of current is noted, and attention called to an unsymmetrical broadening and reversal. Somewhat later reference is made to the work of Exner and Haschek on the displacement of spark lines.

"They traced these displacements, directed mostly toward longer wave-lengths, to the different density of the metallic vapor. With good reason Eder and Valenta objected that these displacements were only apparent. * * * They photographed arc and spark lines im-

[14] Annalen der Physik — Band 29 (1909).

mediately above one another with different exposure times. The long exposures seem to give a different center of intensity from the short, if a line is unsymmetrically broadened to one side; whereas on the other hand the real center remains clearly in the same position only in the case of sufficiently short exposures. The long and short exposures play the same rôle, however, as a greater or smaller density of metallic vapor; therefore the shifts observed by Exner and Haschek are to be considered only as apparent. Exner and Haschek then tried to maintain their theory by referring the cause of the shifts to changeable satellites, which cannot be resolved by a Rowland grating and might therefore produce a shift. They studied the arc lines of a series of elements by means of a 15 plate echelon and made the astonishing discovery that a satellite often appeared upon the red side of the line, especially when the arc flickered. With the plane parallel plates at my disposal, which are more efficient than a 15 plate echelon, I have been unable to verify the satellites which they reported." * * * "It is possible that the satellites seen by Exner and Haschek with the flickering of the arc arose from impurities in the carbon and the metal. It is more probable, however, that they must be regarded as ghosts. Ca λ 4527 is supposed to be simple, but with a satellite arising on the side of greater wave-length upon the flickering of the arc; whereas I found no satellite near this strong line. On the contrary, I observed a weak satellite of greater wave-length near Ca λ 4586, while Exner and Haschek did not. Ca λ 5270 is supposedly a triplet, in which with weak current the middle line is the brightest; with strong current the two lines toward the red are the brightest. All my photographs show this very strong line to be single; furthermore, Cu λ 5218 is supposed to have a red companion which grows more rapidly than the head-line as the current is increased; I always found this very strong line to be single. This very line seems to me proof that Exner and Haschek were deceived by ghosts in their echelon. For if the head-line is not very strong, the ghost can scarcely be seen; if the main line becomes stronger, the ghost comes out more strongly; with further increase in intensity, the main line, however, seems to gain less rapidly than the ghost, since the eye (Exner and Haschek make visual observations only) cannot distinguish differences in great intensities so accurately as in the case of small ones. Nutting has also used the ordinary arc for creating spectrum lines and worked with an echelon of 30 plates, of $1\frac{1}{2}$ cm. thickness. The same remarks as above made are valid in case of the use of the carbon arc."

Janicki reviews Nutting's results, characterizes them as extraor-

dinary; states that they should have aroused Nutting's suspicion and regards them as due to ghosts which become visible when the intensity of the source is sufficiently great. He writes: —

"Thus, according to Nutting, the red *Cd* line, the red and the blue *Zn* lines form triplets; whereas, even with the greatest intensity and the most varied sources of development, it is just these very lines that have always been found to be unquestionably single by Michelson, Fabry and Perot, Hamy, Gehrcke and van Baeyer, and myself. * * * Nutting's echelon had about the resolving power of the plane parallel plate C and did not approach that of plate H, so that the objection cannot be raised that he was able to make closer observations by reason of having a finer instrument. According to him all five prominent silver lines are compound, and indeed, both triple and quadruple, while the plate H even with the greatest intensity shows no sign of satellites. * * * The characteristic line-structure remains the same, no matter how the spectrum is produced. This is confirmed by the agreement of the observations of the lines of *Cd* and *Zn*, where it makes absolutely no difference with whatever instrument one observes and no matter how the spectrum is produced. * * * That the designation of the brightness of the satellites sometimes varies, as in *Cd* λ 4800, is immaterial, since the satellites are weak and the differences in their intensity very slight."

Here follows a discussion of unsymmetrical broadening noted with the Rowland grating by Kayser, Rowland and others. The statement is made that "a good Rowland grating would not resolve an unsymmetrical reversal the components of which, like the chromium line, are 0.043 Ångstrom units apart, and the resultant apparent shift about 0.02 Ångstrom units." There follows a reference to the work of the writer who, with Avery, made certain measurements upon two titanium lines. He writes: —

"They found an average shift of 0.019 and 0.018 Ångstrom units for the two titanium lines $\lambda\lambda$ 3900.7 and 3913.6. In the mean taken from both observers, the minimum and maximum shifts for the line λ 3900.7 are found to be 0.009 and 0.038 Ångstrom units. This very circumstance seems to me to indicate that Kent and Avery were dealing here with unsymmetrical reversals like those of chromium and calcium, reversals which their grating would not resolve and which appeared to them as line-shifts."

General Description and Arrangement of Apparatus.

An echelon spectroscope and a constant deviation spectroscope of the Hilger pattern were ordered of A. B. Porter of the "Scientific Shop," the echelon having 33 plates, a 1 mm. step, 34 mm. height of plate and about 15 mm. thickness, and the lenses of the constant deviation and echelon spectroscopes being of $1\frac{3}{4}''$ and $2''$ diameter and $17''$ and $20\frac{3}{4}''$ focal length, respectively. The constant deviation prism proved to be of insufficient aperture to fill the echelon, and was therefore sent to Hilger for a new prism.[15]

The echelon itself finally appeared to be a poor instrument and wholly unfitted for first-class work; for, upon final adjustment, the green mercury line λ 5471 showed a false pattern and there also appeared in certain zinc spark lines a distinct pattern which the writer, in view of the false satellites in the mercury line, at first deemed likewise spurious, inasmuch as a smaller and less powerful echelon made by Petitdidier, and kindly loaned by Professor Goodwin of the Massachusetts Institute of Technology, did not show it. This was later identified with Nutting's "peculiar fluted appearance, characteristic of spark lines".[16]

The Porter instrument was finally sent to Petitdidier for overhauling. Three plates were taken out and all were adjusted so that the step was more uniform. The instrument again showed both patterns, the mercury line pattern being false. Many months were thus lost with these various difficulties. At length it was decided to continue the work with the borrowed Petitdidier echelon, an excellent instrument, although of only 20 plates, total aperture $27 \times 15\frac{3}{4}$ mm., step $\frac{3}{4}$ mm. and $14\frac{3}{4}$ mm. thickness of plate.

The apparatus generally employed was, then, the Petitdidier echelon and Porter constant deviation spectroscope with a prism fitted by Hilger.

The spark was generated by a Holtzer-Cabot motor-generator set, the alternator of 4.5 K. W. giving 60 complete cycles per second and feeding a 5 K. W. transformer (of ratio of transformation 110 to 30,000) in the secondary of which was a condenser of 0.0226 microfarads, which discharged, at times through various inductances, over a spark gap generally set horizontal.

Two methods of producing the arc were employed, one giving what

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15 Professor Porter died within a short time after the instrument was delivered.

16 Nutting, Astrophysical Journal, **23**, No. 1, Jan. (1906).

we may call the Pfund arc,[17] between two iron rods, the upper, the negative terminal, being 5 mm. in diameter and pointed somewhat, and the lower, the positive, being 16 mm. in diameter, the current varying from about 1 to 9 amp. and the E. M. F. of the circuit being 220 volts; and the other a 110 volt circuit arc between carbon terminals, the lower being positive, and the values of the currents used being within the above limits. In both cases the positive terminal was supplied with small pieces of the necessary metal, ordinary commercial zinc. The echelon image was magnified about $3\frac{3}{4}$ diameters by a Bausch and Lomb microscope.

Two shutters were used, at first a very light wood and wire arrangement, having two sets of openings of three and two openings respectively, placed in the focal plane of the echelon spectroscope; and finally a shutter of cardboard, having two sets of openings of two and one openings respectively, placed over the slit of the constant deviation spectroscope (this method giving good results, as the echelon spectroscope slit was set accurately in the focal plane of the telescope of the constant deviation spectroscope). The echelon was covered with a cotton lined box to prevent temperature changes, which were never more than 0.1° C during any one set of exposures and usually much less. The photographic plates generally used were Seed Gilt Edge #27, in some cases double-coated; the developer generally normal rodinal solution.

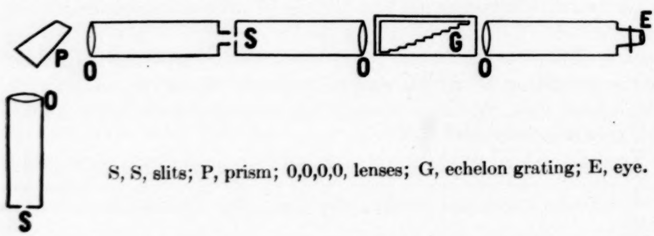
In adjusting and testing the echelons a Cooper-Hewitt mercury lamp, kindly loaned by Mr. William Sawtelle of Harvard, was used.

The two inductance coils used were as follows: —

(a) A coil having three layers as described on page 186 of the *Astrophysical Journal* for October, 1905.

(b) A commercial coil of annunciator wire, weight about 8 lbs., size of wire #18 S. W. G.

The arrangement of the apparatus is shown in the figure.



S, S, slits; P, prism; 0,0,0,0, lenses; G, echelon grating; E, eye.

17 Pfund, Astrophysical Journal, **27**, 296, May (1908).

General Method of Procedure.

Before describing the work in detail it may be stated that the general procedure was to set the echelon at the position of greatest efficiency, such that its axis was parallel to that of the collimator and telescope.

A vertical arc or horizontal spark image was thrown upon the slit and studied visually under numerous and widely different conditions. When a photographic comparison of the two sources was desired, a shutter was used.

Details of the Investigation.

Preliminary comparison of spark and arc. At the outset an attempt was made to compare the position of the image of a highly disruptive spark with that of the arc. This was soon found to be impossible because of the fact that the lines given by a disruptive spark between terminals of the pure metal were not sufficiently monochromatic. Their images given by the Petitdidier instrument cannot be distinguished from those given by the corresponding region of the spectrum of a Nernst lamp (see Plate **1**, 52) and the position of the maximum intensity is a function of the condition of the echelon whether purely of a single or purely of a double order nature at the temperature of the instrument. The only cases in which this method would apply are those in which the spark line is more nearly monochromatic and the condition is absolutely that of a single order. Even then the form of the intensity curve for white or not fully monochromatic light would have to be known.

Visual study of arc lines.[18] As the conditions in the arc and the resulting structure of the lines of the spectrum often change very rapidly, it appeared to be of interest to study these three strong zinc lines visually. A study of this sort was made, an assistant keeping the arc image on the slit and recording the structure of the line as dictated to him. From various sets of observations, many of which are mutually confirmatory, the conclusions given below may be drawn,

18 These visual observations were made in a wholly unprejudiced state of mind for, although the papers of Nutting and Janicki referred to had been read when they were first published, the details of the same had been quite forgotten by the writer of this paper.

these being, of course, modified by the condition of the echelon, whether of absolutely single or double order, or part way between the two. However, interpreting the pattern is a simple matter in either case. The echelon was so placed that in the field of the microscope the lower orders lay at the left, the higher at the right.

Zinc 4810. Upon starting the arc after a fresh piece of zinc was put in, the whole field resembled that of a polychromatic source, except that the normal diffuse echelon image was marked by several fine lines similar to the pattern shown in Plate **1**, 12, whether the position of the echelon for monochromatic light be that of single or double order. This structure always accompanied the arc when noisy, and was present in 4722 and 4680, as well as 4810. It is clearly visible in arc lines with the Petitdidier instrument and is similar to the "fluted appearance" of spark lines. At low current and the single order condition, eight components were visible in 4810, the two outermost poorly marked; the two innermost the sharpest of all. As the vapor became less dense, the structure became less extensive. There appeared two lines strongly marked, lying between two other wider, less intense and less sharp satellites. Then the two outer satellites faded, the stronger, inner pair at times receded from each other and then again approached. Finally the reversed region (if, indeed, we are justified in speaking of the phenomena as a "reversal") disappeared and the two lines merged into one, which eventually became a single, narrow line.

The above phenomena were noticed in the Pfund arc at 2.5 amp., with the upper pole (in error) positive. The condition was the double order one, the lower order being slightly stronger. The same phenomena appeared, however, at single order condition, and with lower pole positive.

At 3.4 amp. at another temperature such that the condition was nearly single order, and with the lower terminal positive, the same general phenomena appeared, but when the two line structure was present and the vapor density was decreasing, the *right component became weaker than the left;* whereas when judged by the fact that the adjacent order was stronger, it should have been the stronger of the two. However, *the right component sometimes appeared stronger than the left* and was generally broader. At this point the current was reduced to 1.1 amp. and the right component, although visible near the lower, or positive terminal, disappeared at the center of the arc, the line there being single.

At 5.5 amp. and the lower pole negative, the phenomena of 2.5

amp. were noted, but upon change of polarity and in the single order condition, the fluting changed into three components, the one lying toward the red being the faintest of the three; moreoever, at times six components appeared, the four toward the red being well marked.

At 8.8 amp. the changes were sudden and well defined. The condition was nearly that of the single order, the higher order being slightly stronger. The central component was lacking and the four side components appeared far apart, the two innermost being the strongest. Then at times the central line appeared, attended by two hazy satellites, the left one of which was often the strongest of all three lines. A sudden change here occurred to a very broad image, showing no structure. New zinc was then supplied and there eventually appeared two well-marked lines far apart; these gradually approached each other, a line developed between them, and all three of these lines were at times of the same intensity. Finally, with lessening vapor density, the central component became stronger and the two outer ones shrank toward it.

Zinc 4722. Current 1.3 amp. single order condition. The same general phenomena obtained following the first fluting, which was poorly marked. There appeared two lines, the left a little stronger than the right. These eventually reduced to a single line.

At 2.5 amp. there appeared a single line between two faint satellites. The right component of the three was stronger than the left at certain times; whereas, the arrangement of the orders was such that it would be weaker. With low vapor density the system became a single line.

At 3.5 amp. three lines of nearly equal intensity appeared, the two on the outside somewhat fainter than the central one, which last was the sharpest of all. The outside components often became broader and finally there resulted one single, sharp line with a faint suggestion of side lines at times of greatest brilliancy.

At 5.5 amp. and nearly a double order condition, a central component and two broad satellites were found.

At 8.8 amp. and using carbon terminals, in the single order condition, at first the field showed no structure, then followed the fluting, then there appeared three lines, the right and left strong, the central one weak and diffuse. Finally the left component disappeared, the central one became as intense as its fellow; then the two merged into a single fine line.

Zinc 4680. At 1.2 amp. and a nearly double order condition, after the fluting there followed a condition marked by two components nearly equal in intensity, followed by a single line.

At 2.5 amp. the left component appeared a little weaker and the lines were less sharp than with less current. At low vapor density there appeared a single line, slightly hazy on both sides. With small amount of vapor and in double order condition, the lines appeared hazy, and no reversal was to be seen. This line, 4680, has, however, been observed at this current in single order condition as a single line with two side components which broadened at certain times, all three lines broadening and receding from each other.

At 3.5 amp. the two components were far apart, and equal in intensity. With small amount of vapor the reversal was less well marked.

The results of this visual study of the arc may be summarized as follows: —

(1) All three lines are at times single.

(2) All have been observed "reversed" but,

(3) 4810 and 4680 are generally double or quadruple, while 4722 is generally triple, and,

(4) All are still more complex at times and show asymmetry, but this asymmetry is no more often marked by stronger *red* satellites than *violet*.

Visual study of the inductance spark lines. A visual study of the spark with inductance showed that the conditions could in this case be more easily controlled and were more steady.

4810, in a nearly single order condition, the right order of the three being stronger than the left, with coil (b) as inductance in the condenser discharge circuit, showed two lines, the right component distinctly weaker than the left when the arrangement of the orders would, if the two components were intrinsically of the same intensity, make this right component the stronger.

The central part of the image was under observation. This right component, however, appeared stronger when the end of the spark image was thrown upon the slit. With no inductance the fluting was *faintly* visible (it had not been observed previously with the Petitdidier instrument [19]) for the gap was small so that the spark burned quietly.

4722 showed the fluting more clearly than 4810, and with inductance, the condition being nearly single order, there appeared two bright central lines which were nearly equal at times. Whenever unequal, however, the left line was the stronger. At the end of the image near the terminals the line broadens out and resembles the disruptive spark.

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[19] See page 97.

4680 in the double order condition showed the fluting faintly at times, while with inductance the line appeared almost single, the "reversal" being almost invisible.

This visual work with the spark shows: —

(1) That at *high* inductance 4810 and 4680 are generally double; (4810 has been photographed as quadruple, and, *with less inductance,* as a quintuplet and a triplet) and 4722 triple.

(2) That here we have a definite asymmetry, controllable and regular, a relative increase in intensity of the red satellites when the end of the spark gap is used. This is fully confirmed by the photographic study. (See discussion below and Plate **1**, **71** (a), (c), and **111** (b).)

PHOTOGRAPHIC STUDY OF ARC AND SPARK LINES AND A COMPARISON OF THE TWO.[20] Among others the following photographs were taken with the Porter echelon:—

The "fluting" not visible in all disruptive spark lines.

12. 4722. Spark without inductance. Center of 4 mm. gap. Shows fluting.

16. *Zn*4924. Without inductance. Center of 4 mm. gap. Shows no fluting. This may be an "air" line, however.

The following photographs were taken with the Petitdidier echelon:

A general comparison of the images of a line as given by different sources.

28. 4810. Pfund arc through two of the openings of the five opening shutter; spark through three openings. Arc current, 0.9 amp. Spark without inductance. Gap 2 mm. and in series an auxiliary gap of 4 mm. Exposures: arc 20 seconds, spark 2 minutes. Compares the pattern and position of arc and spark images, under the double order condition. Confirmed by other similar photographs. However, we cannot tell with the echelon a disruptive spark from an arc burning on a heavy current, as is shown by 36.

32. 4680. Similar to 28. Compares the arc and spark images under single order condition. Confirmed by other similar photographs.

36. 4810. Inside 110 volt arc of about 10 amp. between Pfund terminals and *very dense* vapor. Outside Pfund arc, 1 amp. Compare 28.

52. 4810. Center of 4 mm. gap of disruptive spark, inside opening of three opening shutter; Nernst lamp (in neighborhood of 4810), outside openings. Exposures: Nernst, 1 minute; spark, 15 seconds. Shows that the two cannot be distinguished.

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20 For the photographs which have been reproduced see Plates **1** and **2**.

Inductance spark structure.

70 (a). 4810. Single order condition. Center of 3 mm. gap. Coil (b) in circuit. Exposure: 30 seconds. Notice four components, the two outermost faint.

Inductance spark structure and power in circuit.

81 (b) and (d). 4810. Single order condition. Center of 1.5 mm. gap. Three layers of coil (a) as inductance. Two exposures of 30 seconds each: (b) at 20 amp. and 1 hectowatt; (d) at 50 amp. and 2 hectowatts. These show that approximately doubling the current, and the power in the primary of the transformer has little, if any, effect upon the structure. This is confirmed by another photograph in the case of 4722.

Inductance spark structure as a function of the part of the image viewed.

71 (a). 4722. Single order condition. Electric conditions as in 70 (a). Exposure: 25 seconds. Three components are apparent on the original negative, but the one toward the red is very weak.

71 (c). 4722 Same as (a) but near end of image. Exposure: 35 seconds. Notice new component toward red not due to inequality of exposure, for the main component is just as bright in 71 (a) as in 71 (c). This effect is confirmed for 4810 by another photograph and still further by:—

111 (b). 4810. Center of photographic plate, central part of 4 mm. spark gap; outside of plate, end of gap. Coil (b) as inductance. Notice the new component to red in the exposure of the end of the gap. The original negative shows still another component toward the red. Note further that despite the fact that the photographic image of the central part of the gap is the denser of the two, the components appearing are but two in number. Single order condition with the left of the three central orders slightly *stronger* than the right, giving a condition *unfavorable* for the appearance of components to the right! This is confirmed by three other sets of exposures.

Effect of using an alloy.

88 (a). 4810. Single order condition, center of 1.5 mm. disruptive spark between brass terminals. Shows that the line structure is simple although a continuous pattern is present with it, and that disruptiveness in itself is not the only controlling factor. Other exposures with 5 and 9 mm. gaps gave the same results.

89 (b). 4810. Same as 88 (a) except that three turns of inductance were inserted. The result is a single fine line.

89 (c). 4722. Same as 89 (b). Two fine lines, just separated, appearing on the original negative. Photographs 89 (b) and 89 (c)

thus show that with an alloy and inductance the structure is rendered very simple and the light even more monochromatic than with the lower voltage arc.

Comparison of arc and disruptive spark.

48 (c). 4680. Pfund arc at low current shown by two openings of the five opening shutter: end of image of a disruptive spark of 3 mm. gap with a 4 mm. auxiliary gap in series, shown by three openings. Double-coated Seed, gilt edge 27 plate. Hydrochinone developer. Exposure: arc, 15 seconds, spark 1 minute. Note that there is structure in the spark and that it lies to the right, the region of longer wave-lengths. See especially the middle of the five shutter openings. This is confirmed by two other sets of exposures. The reproduction is poor, owing to the fact that the structure is not strongly marked, and is obscured by a continuous pattern.

Comparison of arc and inductance spark.

85 (a). 4810. A comparison of an inductance spark outside (inductance, three layers of coil (a); exposure, 30 seconds; and center of gap) with Pfund arc inside (low current and exposure 5 seconds). Single order condition but with the stronger of the two adjacent orders toward the violet. Notice that the maximum intensity of the structure lies toward the red in the spark in comparison with the arc. This is confirmed by another set of exposures in which the arc was given relatively greater exposure time. Of course if another part of the arc had by chance been used, the result might possibly have been different. And again, greater arc current might have made some difference in the structure and further, as the rapidly fluctuating conditions in the arc change the structure, the distribution of energy might at another instant have been different. But further exposures are confirmatory with respect to 4810, and show a like phenomenon in the case of 4722; and still others are confirmatory with respect to 4722, and show a like phenomenon in the case of 4680. Further, two other sets of photographs taken some days later, confirm these results for all three lines; and two more using carbon terminals and a 3 amp. current show the same effects in all three lines. And again four other sets taken upon still another day, with a 220 volt, 3.3 amp arc between carbon terminals, give in every case the same results for these three lines.

Such agreement proves that the effect cannot be fortuitous. However, as the inductance spark is steadier and easier to control, it is well to compare sparks having different inductances in circuit:—

Spark line structure as a function of the inductance.

78 (c). 4810. Between single and double order condition. Center of 1.5 mm. gap. Three layers of inductance coil (a). Exposure: 1 minute. Two main components. Note that the right component of the quadruplet is as strong as, or stronger than the left, when the position of orders is such that it would be weaker. This fact is confirmed by other exposures.

79 (e). 4722. Between single and double order condition. Electric conditions as in 78 (c). Exposure: 1 minute. Shows three main components.

80 (a). 4680. Between single and double order condition. The electric conditions are as in 78(c) and 79(e). Two main components. Exposure: 1 minute.

65 (b). 4810. Single order condition. Center of 4 mm. spark gap under different conditions. Outside, no inductance, 5 seconds: inside coil (b) in circuit, 45 seconds. Notice the two side components in the inductance spark image.

68 (a). 4722. Single order condition. Electric conditions, similar to 65. Note inequality of intensity of inductance line components. Exposures: 30 seconds with inductance and 3 seconds without.

94 (c), (d), and (e). 4810. Single order condition. Center of a very small gap — less than 2 mm. Three, two and one layers of coil (b), respectively.

96 (c), (d), and (e). 4680. Double order condition. Same set of operations as in 94. Notice in both plates a continuous increase of intensity of the old components lying toward the red and the development of new ones as the inductance is decreased. Another photographic plate (numbered 95) clearly confirms this for 4722. On all three, 94, 95 and 96, there were also taken shutter comparisons showing the relative positions of the components given with one, two and three turns. These all show that the component coming up with decrease of inductance is the one toward the red: the component toward the violet retains its position while its intensity becomes relatively less. The effect of removal of inductance is similar to that obtained by moving up to the end of a somewhat longer gap leaving the inductance the same. (See 111b).

The conclusions to be drawn from the photographic study are:—

1. That it is impossible by means of the echelon grating to compare the positions of maximum density of any but quite monochromatic sources, whether the condition be either double or single order.

2. That it is impossible in general to distinguish the images given

by a Nernst lamp, an arc of great vapor density, and a highly disruptive spark between terminals of the pure metal.[21] These sources give, in fact, nothing but the so-called "diffraction" as distinguished from the "interference" pattern.

3. That inductance, even in small amounts, is extremely efficient in reducing the intensity of the continuous or diffraction pattern and producing structure in the spark image.

4. That the structure varies with the part of the inductance spark image used whether end or center; the end showing an enhancement of the intensity of the components lying toward the red.

5. That as the value of the inductance is increased, the red components in the structure become less intense.

6. That even a disruptive or non-inductance spark between brass terminals shows structure in the zinc lines studied and that, if in addition inductance be inserted, the resultant lines are as sharp, or even sharper, than those given by a low current arc.

7. That a small amount of vapor in the arc, even with fairly high current (e. g. 8 amp.) produces conditions favorable to structure other than the fluting which occurs when the arc is heavily charged with vapor and is noisy.

8. That on all plates obtained upon which the positions of the components of the spark with small inductance are compared with the positions of the components of the arc at low current (about 3.3 amp.) the center of gravity of the spark structure lies further toward the red than that of the arc.

General Conclusions.

That conflicting results were obtained by Janicki and Nutting is probably due to the fact that different sources of light were employed. The structure Nutting describes is unquestionably real. Certainly echelon gratings may give ghosts. That the Petitdidier instrument used in this investigation is free from such, is shown by the fact that the green line of mercury shows no false lines.

Further, from the visual observations made upon arc lines, it is perfectly clear that the "ghost" argument will not explain the endurance of a satellite or its increase in intensity, when a formerly brighter line grows fainter or disappears entirely, nor, specifically,

21 This is true of the spark only when the echelon is not powerful enough to resolve the components of the fluting.

a case such as that recorded on page 101 under Zn 4722 at 8.8 amperes. It is impossible for the main line to disappear and the ghost remain; and again, even if ghosts were present, there is no reason why these should appear in the case of any one line with the spark as a source, and not with the arc. The presence of neither a symmetrical nor unsymmetrical ghost structure could produce the enhancement of the red satellites in the spark.

A certain objection may, however, be made: namely, that the presence of the diffraction pattern between the orders when the instrument is in a double order condition, might cause satellites which are of low intensity to appear (when otherwise they would not) in much the same manner as fogging a photographic plate will carry the exposures of "low lights" up along the intensity curve so that they will become visible.[22] In response to this objection, it may be said that the satellites in question are not always of low intensity, either visually or photographically; and they even come up on the *right* side when the diffraction pattern lies to the *left*.

We must conclude, then, that there exists for some unknown reason a fairly progressive increase in the intensity of the red satellites of these three zinc lines with decreasing inductance. There follows at once the unsymmetrical broadening to the red of the images given by instruments of less resolving power, namely, prism or grating spectroscopes.

The unsymmetrical satellite system may be produced by the high potential gradient in the spark; why, the writer, of course, cannot state. Disruptiveness is not a determining factor, for in the same spark we obtain from different parts of the gap different line structure. Vapor density probably does not of itself determine structure, but may influence the potential gradient. In the arc high density seems to produce a tendency toward complexity of structure, but not an asymmetry of a regular or enduring type.

All the writer's observations, both visual and photographic, confirm the results obtained by Nutting, dealing with arc structure. The results of this study also confirm the shifts found by the writer[23] to exist at lower dispersion, shifts,—great at the end of a fairly large gap of a non-inductance spark between terminals of the pure metal, lessened or removed entirely by the addition of inductance, and by the use of the central region of the gap; and lessened also by the use of an alloy. In this former work the standard of reference employed

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22 R. W. Wood actually used this method.

23 Astrophysical Journal, **22**, No. 3, Oct. (1905).

was a carbon arc of somewhat greater current than here used, but the amount of vapor was never great, only small bits of metal being inserted in the arc, and the exposure always being made when it was burning quietly. These two sets of standards were probably much the same. Still, assuming them different, if the potential gradient determine the enhancement of the red satellites and we accept Nuttings classification of gradient, from low to high the order being, (1) heavy current arc, (2) low current arc and inductance spark, (3) high capacity and non-inductance spark, then the assymmetry of satellites (and resultant shift) obtained in this investigation with low current arcs as standards would be even less than that found with the somewhat higher current arcs previously used. However, as stated above, in the arc there seems to be no regular, controllable nor enduring enhancement of either red or violet satellites.

Janicki's suggested explanation of the shifts obtained — namely, as "unsymmetrical reversals like those of chromium and calcium, reversals which their grating would not resolve and which appeared to them as line-shifts" must then be replaced by this enhanced satellite theory.

The distances between the satellites in Plate **2**, 48 (c) are approximately 0.05 Ångstroms. We may then say that the removal of two layers of inductance in coil (a) has shifted the center of gravity of the line at least 0.02 Ångstroms. In the extreme case then, with no inductance in the circuit, the shift might easily be in the neighborhood of 0.032 Ångstroms, as formerly obtained.

The writer wishes to record his appreciation of the kindness of Professor Goodwin of the Massachusetts Institute of Technology in loaning his Petitdidier echelon. To the Rumford and Bache Committees, and a personal friend, Mr. J. DeL. VerPlanck, the writer is indebted for funds which made this investigation possible. In the actual work of obtaining the results he wishes to acknowledge the faithful assistance rendered by various students, especially Messrs. Walter F. Burt, Russell T. Hatch, Charles H. Smith and Carl K. Springfield.

Physics Laboratory, Boston University,
June, 1912.

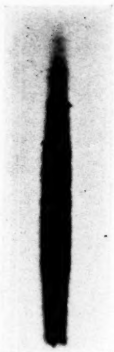
12

The following negatives, on Plates **1** and **2**, represent approximately a threefold enlargement of the image as photographed or a twelve-fold enlargement of the echelon image.

The region of longer wave-lengths lies to the right.

12 and 16 were taken with the Porter echelon; 28 to 96e with the Petitdidier instrument.

Much of the detail existing upon the enlarged negatives is not apparent in the reproductions herewith shown.



16

28

32

36

52

70a

81b

81d

71a

71c

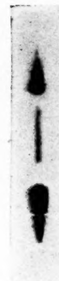
111b


88a

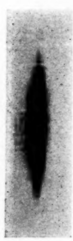

89b


89c


48c


85a


78c


79e


80a

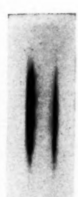

65b

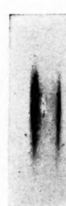

68a


94c


94d


94e


96c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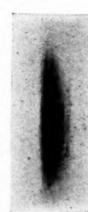
96e

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